SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

31p.

N64 33778
(ACCESSION NUMBER)
31
(PAGES)
CR-56245
(NASA CR OR TMX OR AD NUMBER)
(THRU)
1
(CODE)
12
(CATEGORY)
FACILITY FORM 602

OPTICAL SATELLITE TRACKING PROGRAM

Carried out under grant number NsG 87/60

from the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OTS PRICE
XEROX $ 2.00 FS
MICROFILM $ .50 MF

Semiannual Progress Report No. 9

UNPUBLISHED PRELIMINARY DATA

CAMBRIDGE, MASSACHUSETTS 02138

[redacted]

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Semiannual Progress Report No. 9

July 1 through December 31, 1963

Project Director: Fred L. Whipple

Cambridge, Massachusetts 02138

[redacted]

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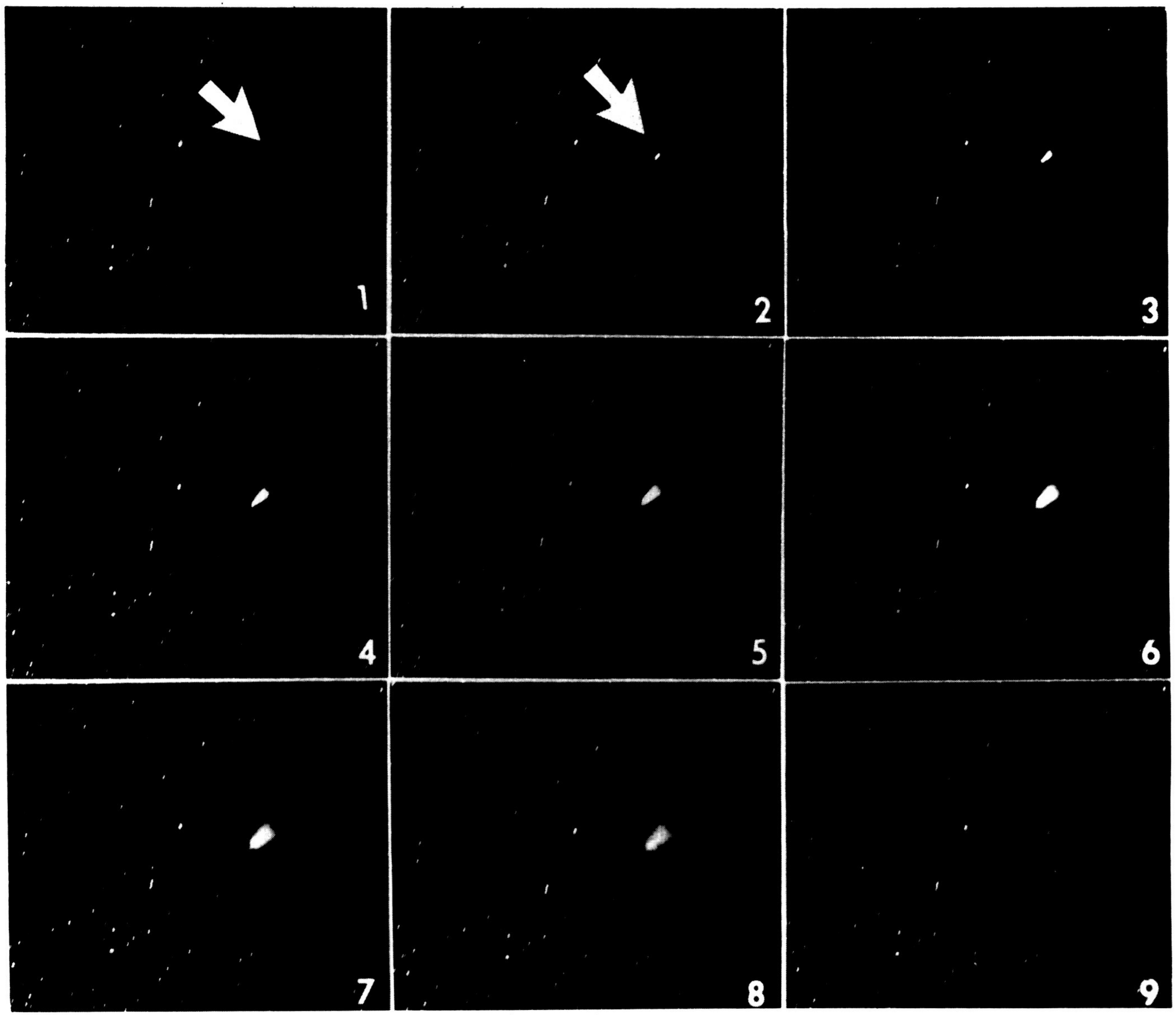

Frontispiece.--The SAO South African camera station photographed the firing of the apogee-kick motor that sent Syncom II into near synchronous orbit on July 26, 1963. The 28-inch diameter spacecraft was some 22,300 miles above East Africa when the photos were taken. (NASA photograph)

HIGHLIGHTS

An important result of recent atmospheric investigations has been the determination of the atmospheric heating in the auroral zones. Jacchia and Slowey find that on geomagnetically quiet days the upper-atmospheric temperature in the auroral zones is essentially the same as that at the equator and that the heating that accompanies geomagnetic perturbations in the auroral zones is four or five times greater than the heating during these perturbations in low latitudes. To further these investigations at high latitudes NASA launched Explorer 19 on 19 December 1963. Jacchia participated as one of the chief experimenters using the data from this balloon satellite.

To obtain a detailed representation of the earth's gravitational potential, recent determinations by Imre Izsak of the coefficients of the tesseral harmonics and by Yoshihide Kozai of the zonal harmonics have employed vast bodies of data for several satellites. One of these was ANNA. Use of the data from flash as well as solar-illuminated observations gave a slightly better determination of its orbit than that obtained without the flash data. Agreement between flash and solar-illuminated observations was very satisfactory.

Simultaneous observations of ANNA were made by two or more camera stations to provide a means for more precise measurement of distances between land masses. Corrections in the coordinates of the camera stations have already been accomplished by this method.

Information on the geometrical shape of the earth and the relative location of points on it can be obtained from accurate determinations of the positions of satellite-tracking stations. SAO uses two methods to improve the accuracy of station coordinates--one dynamical, the other geometrical. The most recent application of the dynamical method adjusted the station coordinates at the same time as it determined the coefficients in the geopotential representation. A paper by George Veis, using a somewhat different approach and some 40,000 observations, is in preparation.

Under a special co-operative agreement with Sir Bernard Lovell's Nuffield Radio Astronomy Laboratories at Jodrell Bank, England, we have been conducting studies of flare stars, using the Baker-Nunn cameras and the 250-foot radio telescope at Jodrell Bank. These simultaneous radio-optical observations were undertaken to discover possible similarities between the flare activity on distant stars and that on our own sun. Data from several small events are now being correlated.

During the period July 1 to December 31, 1963, SAO was responsible for tracking Explorer I, Vanguard II, Vanguard III, Explorer VII, Echo I, the Echo I rocket body, Explorer VIII, Explorer IX, Tiros VI, and Explorer XIX. In addition, the Observatory provided tracking back-up for launches and produced special predictions and observations for SAO staff scientists and other agencies that requested them.

The tracking stations received 45,449 predictions of satellite passages, from which they made 17,877 successful observations. The Observatory's Photoreduction Division determined 13,363 precise satellite positions.

Outstanding performances of the Baker-Nunn system included: photographing mirror reflections from Telstar II; sequence photography of the Syncom II apogee-kick-motor firing; and photographing and detecting extraneous parts of Centaur AC-2, later determined to be nose farings carried into orbit with the payload.

DATA ACQUISITION

STATION OPERATIONS

(Baker-Nunn camera stations)

During the period of this report Station Operations continued to track satellites both on assignment from the National Aeronautics and Space Administration and to meet special needs of Observatory scientists. In 1963 we sent 82,734 predictions to the Baker-Nunn camera stations, which made 32,895 successful observations (see table 1). The system average for the year was 40 percent.

We are continuing the programs to renovate the Baker-Nunn camera optical systems and to improve the operation of the Norrman Time Standard through better training and maintenance.

We have continued our planning for a station in Ethiopia. Specifications are being drawn up for the buildings, and a bid for the roof has been requested from Predesign Building Company.

The prototype precision timing system is still in routine operation at the Florida tracking station. We forwarded specifications for production models to the Electronic Engineering Company of California (the manufacturers of the prototype system) to obtain a price quotation. We are studying a proposal received from EECo in November and expect construction to begin within the next six months.

Equipment and instrumentation

Basic equipment at the stations operated satisfactorily with routine mechanical and electrical maintenance.

Table 1
Calendar Year 1963

SATELLITES OBSERVED FOR NASA AND SAO SCIENTIFIC INTEREST

Summary of number of passes predicted for each Photographic Satellite Tracking Station, with the number and percent of passes successfully observed in 1963

	New Mexico SC-1			South Africa SC-2			Australia SC-3			Spain SC-4			Japan SC-5			India SC-6			Peru SC-7		
1963	P	S	%	P	S	%	P	S	%	P	S	%	P	S	%	P	S	%	P	S	%
Jan.	424	159	38	730	221	30	620	348	56	406	64	16	406	305	73	391	277	71	578	32	06
Feb.	462	262	57	621	385	62	464	234	50	472	102	22	485	180	37	479	324	68	484	08	02
Mar.	511	260	51	588	327	56	627	371	59	510	161	32	497	136	27	538	326	61	422	83	20
Apr.	564	241	43	527	276	52	568	339	60	569	201	35	571	118	21	540	306	57	343	54	16
May	613	302	49	675	407	60	764	245	32	609	265	44	619	86	14	609	355	58	399	147	37
June	594	370	62	632	303	48	646	286	44	596	283	47	577	80	14	590	120	20	549	269	49
July	995	247	25	517	288	56	510	163	32	960	614	64	976	89	9	987	144	15	540	250	46
Aug.	842	193	23	553	346	63	514	282	55	824	429	52	802	95	12	912	25	3	500	207	41
Sept.	527	273	52	570	302	53	613	338	55	558	321	58	551	45	8	541	207	38	467	200	43
Oct.	576	377	65	706	371	53	696	363	52	575	322	56	574	102	18	558	384	69	582	232	40
Nov.	716	368	52	643	161	25	628	321	51	642	177	28	663	157	24	697	373	54	632	287	45
Dec.	415	248	60	735	215	29	723	363	50	425	080	19	412	147	36	394	277	70	752	170	23
Total	7239	3300		7497	3602		7373	3653		7146	3019		7133	1540		7236	3118		6248	1939	
Av/mo.	603	275	48	625	300	49	614	305	50	596	251	39	594	126	25	603	260	49	521	162	31

SC = number of camera; P = predictions; S = successful observations; % = percent of passes successfully observed

Table 1 (Cont'd)

	Iran SC-8			Curaçao SC-9			Florida SC-10			Argentina SC-11			Hawaii SC-12			Total	Total Percent	
1963	P	S	%	P	S	%	P	S	%	P	S	%	P	S	%	P	S	%
Jan.	398	236	59	348	75	22	413	119	29	138	58	42	363	111	31	5215	2005	38
Feb.	475	155	33	397	146	37	479	103	22	515	270	52	438	255	58	5771	2424	42
Mar.	552	205	37	391	131	34	541	154	28	482	234	49	501	98	20	6160	2486	40
Apr.	541	159	29	410	97	24	529	208	39	450	283	63	462	66	14	6074	2348	39
May	594	199	34	495	108	22	595	154	26	557	220	39	540	187	35	7069	2675	38
June	583	318	55	468	216	46	594	228	38	611	272	45	556	335	60	6996	3080	44
July	978	392	40	793	284	36	936	291	31	549	246	45	851	496	55	9592	3477	36
Aug.	874	306	35	604	212	35	805	256	32	562	237	42	660	412	62	8452	3000	35
Sept.	536	346	65	424	102	24	521	129	25	592	165	28	487	290	60	6387	2718	42
Oct.	569	301	53	418	165	39	562	176	31	707	262	37	467	244	52	6990	3299	47
Nov.	692	266	38	644	141	22	700	201	29	701	262	37	598	303	51	7956	3017	38
Dec.	408	117	29	318	77	24	378	125	33	774	398	51	338	149	44	6072	2366	39
Total	7200	3000		5710	1754		7053	2144		6638	2907		6261	2919		82734	23895	
Av/mo.	600	250	42	476	146	30	588	179	30	553	242	44	522	243	45	6895	2741	40

System Average for 1963 - 40%

Mechanics and optics of Baker-Nunn cameras--We inspected and repaired the cameras in New Mexico, Florida, and Hawaii and overhauled those in Australia and Japan. The mirror at the Florida Station was realuminized in September. We expect to complete work on the mirrors in Curaçao, Spain, Peru, and Japan within the next six months. We hope soon to have a thirteenth mirror ready to circulate in the field to expedite the rest of this work.

We have awarded to the Perkin-Elmer Corp. a contract to refurbish a corrector cell from the Curaçao station. This cell will be installed as soon as possible after its completion in June. The contract also covers fabrication of a protective window to prevent moisture and dirt from damaging the very delicate surface of the corrector-cell element. The first window will be installed in Curaçao along with the refurbished corrector cell. Windows will later be installed at the other stations.

Norrman timing system--We have initiated the use of triggered-sweep oscilloscopes for improved time-signal interpretation in all the stations. An improved WWV receiver has been supplied to South Africa. A Sulzer oscillator has been installed in New Mexico, and similar units have been shipped to Argentina and South Africa. The remaining oscillators have been under test in our laboratories. We are continuing the study of timing inaccuracies as part of a program to detect major sources of difficulty in the existing equipment.

Station vehicles--Argentina has received its 1963 Ford crew-cab, and South Africa its locally purchased 1963 International Harvester panel van. A Willys Wagoneer should arrive in Peru in early February.

Observer training program

To date 22 men have successfully completed the observer training program and have been placed at field stations. The training period provides each man with a broad sample of Observatory activities and actual field experience. Before signing an employment agreement, he can therefore more surely decide whether he is capable of, and interested in, the activities of a tracking station.

During the period of this report 6 new observers successfully completed their training. They have now been assigned to tracking stations. Two experienced observers were trained in the use of new equipment and procedures.

MOONWATCH

During this report period the Moonwatch Program consisted of 15 "precision," 30 "standard," and 150 "limited" teams and independent affiliates. They reported 3805 observations of more than 100 orbiting objects (see table 2).

Special assignments included assisting with the tracking of Explorer IX during a period of instability and the post-launch tracking of the first Centaur and of Explorer XIX. New Moonwatch publications and individaul correspondence were issued to make technical advice and instruction available to visual observers.

We began a study (funded by grant NsG 563 as well as NsG 87/60) of the feasibility of airborne visual observing as a means of tracking decaying satellites. In five flights in USAF C-130 aircraft observers successfully acquired and tracked Echo I and Explorer IX, using standard air navigation equipment.

Table 2

MOONWATCH OBSERVATIONS

Satellite	No. of Observations Received
1958 Alpha	166
Beta 1	1
1959 Alpha 1	55
2	42
Eta	56
Iota 1	38
1960 Beta 2	3
Epsilon 3	29
Zeta 1	11
Eta 1	2
3	1
Iota 1	362
2	217
3	40
4	6
5	31
Nu 1	3
2	19
Xi 1	46
2	2
Pi 2	7
1961 Alpha 1	7
2	1
Delta 1	412
2	13
1961 Delta 3	6
Nu	46
Omicron 1	108
2	58
3	12
others	42
Rho 1	7
Sigma 1	78
4	1
A-Delta 1	31
A-Eta 1	3
1962 Beta 1	11
4	3
Zeta 1	3
2	1
Iota 1	5
Kappa 1	40
Omicron 1	11
2	7
Sigma 1	8
Omega 1	29
A-Alpha 1	34
A-Epsilon 1	7
2	87
A-Xi 1	14

Satellite	No. of Observations Received	Satellite	No. of Observations Received
A-Upsilon	34	22A	11
A-Psi 1	40	B	2
2	5	24A	6
B-Alpha 1	44	B	1
2	81	25A	1
B-Theta 1	10	B	1
B-Kappa	257	26A	11
B-Mu 1	106	27A	14
2	6	29A	1
B-Tau 1	7	30A	44
2	12	D	6
5	2	32A	1
6	30	33A	12
B-Upsilon 1	26	B	38
2	43	35A	4
B-Chi	20	38A	34
B-Psi 1	8	B	21
2	5	C	20
1963 3A	107	39C	1
5A	10	43A	137
9A	67	B	1
B	2	47A	52
10A	12	B	10
B	11	C	4
13A	4	D	6
B	40	F	2
1963 14A	54	G	9
17A	11	50B	4
G	55	53A	12
21A	1	B	6
		Total	3805

TOTAL MOONWATCH OBSERVATIONS through 1963

Period	Number of Observations Received
1963	
Fourth Quarter	1668
Third Quarter	2137
Second Quarter	1903
First Quarter	1327
Total	7035

COMMUNICATIONS

New services and equipment

By October 1 eight of our camera stations were successfully testing the new 222 observational reporting format developed for use with the recently installed IBM-47 tape-to-card machine. In December the 12 Baker-Nunn stations reported 3322 observations on the redesigned passage-record forms. The new system has greatly reduced the time between the receipt of observations and input to the computer.

We requested GSA to install a teletype reperforator in its Miami office to facilitate message handling between SAO and the Jupiter, Florida, tracking station.

Plans

We plan to replace the two Model-19 teletype machines with the newer Model 28 machines for more efficient and flexible operation.

Back-up radio teletype equipment for the Argentina station should be in operation during the next reporting period.

Because the message traffic over our lease-line to Goddard is heavy, we are discussing with NASA Communications Branch the possibility of having the circuit speed stepped up to 100 wpm and of placing the circuit in full-duplex operation.

DATA PROCESSING

DATA DIVISION

The data Division computes predictions of satellite positions for the various satellite-tracking stations; derives orbits from observations made by Baker-Nunn, Moonwatch, or other tracking stations; prepares smoothed and mean orbits (from both field-reduced and photoreduced data) for publication in SAO Special Reports; records information that may affect research on satellite orbital data; publishes predictions, orbital elements, and equator crossings; and handles the routine technical correspondence of the Satellite-Tracking Program. The division is also responsible for preparing and publishing the SAO Star Catalog.

Nominal and revised early-tracking predictions were derived for all NASA launches for the Baker-Nunn cameras and some Moonwatch stations. These totaled 1024 predictions for four objects.

We processed the normal Baker-Nunn, Moonwatch and miscellaneous observations and derived orbits each week, using the Differential Orbit Improvement program. Employing the SCROGE and Ephemeris II programs, we used these orbits to produce predictions for the Baker-Nunn stations and selected Moonwatch sites (see tables 1 and 2). The network regularly tracked 21 satellites, in addition to objects tracked for launch backup and other special interest.

Mean and smoothed orbital elements were derived and published for the satellites listed in table 3. We also published observations of the satellites listed in table 4.

Table 3

Satellite	Special Report Number
1958 Alpha (Explorer I)	113, 117, 120, 126, 142
1959 Alpha 1 (Vanguard II)	113, 117, 119, 120, 126, 141, 142
1959 Alpha 2 (Vanguard II Rocket)	119
1959 Eta (Vanguard III)	113, 117, 119, 120, 126, 141, 142
1959 Iota 1 (Explorer VII)	113, 117, 120, 126, 142
1960 Beta 1 (Tiros I Rocket)	141
1960 Beta 2 (Tiros I)	141
1960 Xi 1 (Explorer VIII)	113, 117, 120, 126, 142
1960 Iota 2 (Echo I Rocket)	119, 141
1961 Delta 1 (Explorer IX)	113, 117, 119, 120, 126, 141, 142
1961 Omicron 1 (Transit 4A)	141
1961 Omicron 2 (Injun 3)	141
1960 Iota 1 (Echo I)	117, 120, 126, 141, 142
1960 Gamma 2 (Transit 1B)	126
1962 Alpha Epsilon 1 (Telstar I)	142
1962 Beta Mu 1 (Anna IB)	142
1962 Beta Tau 2 (Injun III)	142
1962 Beta Upsilon 1 (Relay I)	142

Table 4

Satellite	Special Report Number
1958 Alpha (Explorer I)	114, 130
1958 Beta 2 (Vanguard I)	130
1959 Alpha 1 (Vanguard II)	114, 130, 138
1959 Eta (Vanguard III)	114, 130, 138
1959 Iota 1 (Explorer VII)	114, 130
1960 Gamma 2 (Transit 1B)	130, 137
1960 Iota 1 (Echo I)	115, 131, 137
1960 Iota 2 (Echo I Rocket)	115, 131, 138
1960 Xi 1 (Explorer VIII)	115, 131
1961 Delta 1 (Explorer IX)	116, 132, 137, 138
1961 Omicron 1 (Transit 4A)	116, 132
1961 Omicron 2 (Injun-Solar Radiation 3)	116, 132
1961 Upsilon 1 (Explorer XII)	116
1962 Zeta 1 (Orbiting Solar Observatory)	116
1962 Iota 1 (Cosmos 2)	116
1962 Iota 2 (Cosmos 2 Rocket)	116
1962 Nu 2 (Cosmos 3 Rocket)	116
1962 Omicron 1 (S51/UK1)	116
1962 Omicron 2 (S51/UK1 Rocket)	116
1962 Alpha 1 (Tiros I)	116
1962 Alpha Epsilon 1 (Telstar I)	132
1962 Beta Lambda 1 (Explorer XV)	132
1962 Beta Mu 1 (Anna IB)	132
1962 Beta Upsilon 1 (Relay I)	132
1962 Beta Chi 1 (Explorer XVI)	132

We prepared special predictions for objects of particular interest to SAO and other requesting agencies. These included Syncom II (see frontispiece), Centaur AC-2, Telstar II mirror reflections, and objects expected to re-enter the earth's atmosphere. Predictions and orbital elements of such objects as ANNA, Echo I, and the other balloon satellites were prepared for other tracking agencies that requested them. This service is in line with the terms of the satellite-tracking grant. These predictions usually took the form of look angles. Among the recipients were Mitre Corp., MIT, Lincoln Laboratory, Air Force Cambridge Research Laboratory, Coast and Geodetic Survey, Raytheon, Bell Telephone Laboratory, State University of Iowa, and Goddard Space Flight Center.

The completed program for decoding, checking, and punching observations for computer use was being tested at the end of this period. It is now handling Baker-Nunn data.

The star catalog

The introduction to the Star Catalog is in its final draft. The Catalog, originally completed in the FK3 system, has been put into the FK4 system. Binary tapes have gone through several successful test runs in Washington. The book format of the catalog has been extensively discussed and generally accepted. We have received the necessary modification of the EAI data-plotter and are testing the plotting system. We have also asked the Army Map Service to reproduce the future star charts. A bibliography for future catalog work, which now contains about 1500 entries, was begun. Orientation angles of about 1200 galaxies were determined for charts. Three catalogs of nonstellar objects (two requiring hand-precession) and the FK4 were keypunched. We completed a brief statistical study of the SAO catalog in the FK3 system.

PHOTOREDUCTION DIVISION

In this period the division determined 13,363 precise satellites positions, reduced to A1 time. The SI-ARP preparation program has allowed us steadily to increase in production, despite routine malfunctions of measuring equipment.

Regular reduction of observations increased 12.5 percent over the previous report period. During calendar year 1963 we determined 25,261 precise reductions, reduced to A1 time--an increase of 3,595 (16.6 percent) over the previous year. The total number of precise positions, reduced to A1 time, completed through 31 December 1963 is 68,693.

We have modified a second measuring system to allow use of plug-in program boards. This provides the program flexibility required to deal with an increasing number and variety of "special" measuring projects.

ANNA IB--Special programming and operational changes undertaken in the previous report period enabled the division regularly to produce precise reductions of the geodetic satellite ANNA IB. The astrometric group completed 735 precise positions determined by measurement of flashes of the satellite photographed on Baker-Nunn film. Because of the complexity of the procedures used on reducing images of ANNA IB's flashes, the time expended in preparing and reducing each flash image is three or four times as great as that expended on the images of other satellites.

Routine operations

The film-control section received and cataloged approximately 20,000 films from the Baker-Nunn stations. Of these, 10,522 were evaluated for precise reduction. Our Cambridge storage facility now contains over 111,000 films.

We have continued close participation in the Cambridge phase of Baker-Nunn station observer training. During the period of this report, nine observer trainees spent a total of 76.5 days with members of the division staff, who instructed them in the various phases of photoreduction operation.

Equipment and instruction

We received a special program patchboard and three program panels, which we had prewired as program plugboards for one 829A comparator measuring system.

Plans

We have engaged additional warehouse facilities for our library of Baker-Nunn films. Special shelving will be erected to accomodate 100,000 films, or two to three years' supply at the current rate of receipt of successful films from the stations.

COMPUTATIONS DIVISION

The Computations Division carries out work in applied mathematics and computer programming; operates the existing computer programs; and provides a digital computer facility for SAO staff members. When necessary, it buys time on the IBM-7094 computer at Harvard University.

Projects completed

Numerical integration programs--The research program designed to investigate the effects of the earth's magnetic field on the motion of Explorer XI has been satisfactorily completed. The results will be pubished shortly.

Contour-plotting program--A program to compute and plot the contours of the continents has been completed. As by-products, some general subroutines were developed for use with the EAI dataplotter.

SI-SPOT--This program, written to facilitate reduction of observations of a flashing satellite, has been successfully completed.

GEOD 2-3--These programs to determine X,Y,Z corrections to station coordinates from DOI residuals seem to be functioning well. Aside from some operational considerations, work on the programs is complete.

Periodic and near-periodic orbits--The preliminary integration program to investigate periodic and near-periodic orbits near the critical inclination has been completed.

Projects continued

After the first satellites were launched in 1957, a set of standard forms evolved for reporting observations, distributing predictions, sending TWX messages, and so on. The subsequent development of the Satellite Tracking Program has necessitated many changes in format. In devising new or modified formats, we have revised the output of the prediction programs, the input of the observation-processing programs, and the printed forms used both at the stations and in Cambridge. We changed to the new system on January 1, 1964. Hopefully, this will be the only basic change needed in our formats for some time to come. This change affected many programs:

Differential Orbit Improvement Program (DOI) --We have incorporated the new observation-card format into the DOI and have initiated plans to include effects of the tesseral harmonics in the theoretical orbit. Documentation of this program is almost complete and a write-up should be issued shortly.

Matched-track prediction program (SCROGE) --The output sections of this program were modified to produce the TWX messages in the new 666 format. Phase 1 output was also rewritten. A new control feature was added to the program to help select certain stations.

Astrometric reduction program (ARP) --The input and output have been revised to make optimum use of the IBM-7094 computer; the change, on the average, saves 48 percent of the running time. We continue to improve the more subtle aspects of the reduction process and to improve the deck set-up facilities to aid in running the program. This program has been modified to produce observation cards in the new format.

The preparation program --We are still making minor modifications to this program to increase its capabilities and efficiency. It is essentially in maintenance status.

Star Catalog --Because of the publication of the FK4 system, SAO undertook to convert its existing Star Catalog, then in the FK3 system, to this new system of coordinates before publication. This delay gave us a further opportunity to change the form of publication, from computer 1403 printout to direct production of microfilm on an SC 4020. The five aspects of work on the Star Catalog were

1. Writing and running a program to eliminate duplicate stars from the basic 9-word format tapes. We had previously done this with the 11-word format tapes.

2. Updating the working catalog used in the preparation program to 1963.5, midway in the year in which observations are being reduced.

3. Writing and running a program to convert our catalog from the FK3 system to the FK4 system. This will be completed in the first quarter of 1964.

4. Writing and running a program to produce the output of the Star Catalog in a format suitable for publishing.

5. Writing (incorporating the existing subroutines) and running a program to use the output from the program mentioned in Item 4 to produce magnetic tape suitable for input to the SC-4020 microfilm processor. These tapes will be run on a machine outside SAO. We estimate that it will take 90 minutes of time on the IBM-7094 computer to produce the magnetic tapes of the published Star Catalog.

Ephemeris 0 --Additions to the program enable it, when desirable, to compute and print uncertainties in the orbital position, using the uncertainties in the elements produced by the DOI. Work is in progress for computing the velocities (X,Y,Z) by a numerical differentiation scheme.

Ephemeris 2-2S --These two standard programs from the early days of the tracking program have been combined into one IBM-7094 computer program. This eliminates the time-consuming and operationally awkward process of working under a compatibility program. A revised write-up is in preparation.

Tesseral harmonics --This research program has produced some results but is still under development,as there is not complete agreement about its results.

Automatic processing of observations --This program, written for the 1401 computer, went into full-scale production on January 1, 1964. It can currently handle observations for up to 25 different objects; it accepts input in the new 222,666 formats and produces output in the new observation-card format. We are now reviewing it and are incorporating some modifications. We are working on means to treat other types of observations, such as Minitrack, in the same manner. Since we do not issue predictions for these sensors, we can make no comparison on the basis of prediction, but the other aspects of the program will be pertinent.

Heat-flow values --We are currently writing a program to compute general heat-flow values as a function of longitude and latitude by the use of spherical harmonics.

Simultaneous observations --The program to compute corrections to station coordinates from simultaneous observations awaits further testing. Minor modifications have been incorporated and documentation of the program is forthcoming.

The Newcomb operators --A phase of a large project, the Laplace Coefficients Program, was completed. The cooperating MIT scientist has developed a program to compute Newcomb operators (see Special Report No. 140). We now have run the program on our machine and made some extensions to it.

System Programming --We have successfully converted from the 7090 to the 7094 computer. The conversion did not involve altering the machine hardware, only changing our existing programming systems to make use of these new hardware features. A new and more efficient system, BESYS 4, is now functioning. Some input-output limited programs have reduced running time by as much as 40 percent. New techniques in systems, such as BESYS 4, or modified machines, such as the IBM-7094 computer,have made it possible for us to carry out increasing amounts of computations work without appreciable increase in cost.

Other division projects include the organization and maintenance of a filing scheme for the program write-ups and the program library. We are also constructing a programmer's primer, a training artifice, to help reduce the work of training personnel.

New projects

Specialized integration program --This program integrated the equations of motion in double-precision. By-products are some general Runga-Kutte-Gill double-precision integration subroutines.

Polynomial evaluation by circle search --A general program to find the roots of any polynomial does not exist. We are attempting to produce such a program by employing an improved version of an already-existing mathematical technique.

Minitrack observations --A new format for Minitrack observations has been announced. We are writing a program to process these observations and to produce input suitable for the DOI.

Publications

During this reporting period the Computation Division has issued 15 program write-ups:

1. E. M. Gaposchkin; SIORB1, Orbit Calculation; June 1963.
2. W. Joughin; GIRNIUS, Vector Calculation Routine; June 1963.
3. R. Loeser, INGE, Incomplete Gamma Function; June 9, 1963.
4. B. Benima; LPLCOF, Laplace Coefficients; June 12, 1963.
5. O. Gingerich; BABYLON, Moon-rise and-set in Babylon; June 26, 1963.
6. J. Francis; DATE, Date Routine for FMS; August 1963.
7. J. Cherniack; 1401 Manual: 1401 Subroutines; August 1963.
8. S. Howard; SIMO, I/O for Simultaneous Observation Program; August 1963.
9. J. Cherniack; 1401 Tape Subroutine Package; August 1, 1963.
10. O. Gingerich; AVHYD, A(H) Opacity Routine; August 14, 1963.
11. E. M. Gaposchkin; GIO4, GIO for BESYS 4; September 1963.
12. R. Taylor; BINCOP, 1401 Binary Tape Copier; September 9, 1963.
13. M. Stein; CCLTIM, Accurate Timing Routine; October 1963.
14. E. M. Gaposchkin; FORGI, GIO Input for FMS; October 1963.
15. E. M. Gaposchkin; SIORB2, Many-Satellite Version of SIORB1; October 1963.
16. E. M. Gaposchkin; SATPOS, Satellite Position in Sidereal; October 1963.
17. W. Joughin; CNTPLT, Contour Plotting; October 1963.
18. B. Hartstein; SIPREP, SI-ARP Preparation Program; July 1963.
19. O. Gingerich; AVH2P, $A(H2^+)$ Opacity Routine; October 30, 1963.
20. D. Lautman; OSCELVAC, Coordinate Conversion; November 5, 1963.

RESEARCH AND ANALYSIS

Satellite geodesy

The efforts in this field reported half a year ago yielded a number of significant results. That the related computer programs have been run on the IBM-7094 for several hours per week indicates the amount of computation performed.

In a recent paper (in press) Imre G. Izsak described in detail the adopted computational schemes as well as his results concerning the tesseral harmonics of the geopotential and the corrections to the coordinates of the 12 Baker-Nunn camera stations. We analyzed 15191 precisely reduced observations of 10 artificial satellites to obtain new least-squares estimates for the unknowns in question. The present method seems to yield estimates of geophysical significance for harmonics up to the sixth degree. The results with regard to the camera sites agree reasonably well with those arrived at by the geometrical method of simultaneous observations in cases when the latter are available.

Dr. George Veis analyzed 33087 precisely reduced Baker-Nunn camera observations of 7 different satellites to obtain estimates for the positions of the stations. As in the past, he was assisted by Mrs. Elizabeth Wombwell and Antanas Girnius. His GEO 3 program computes individual corrections to the station coordinates. These data in conjunction with gravitational variations taken from other sources have been used for the determination of the several datum shifts. The following table illustrates the geodetic results:

Table 5

	Izsak			Veis		
	dx	dy	dz(m)	dx	dy	dz(m)
Organ Pass	-10	19	51	1	- 3	- 4
Olifantsfontein	31	64	-10	16	9	- 3
Woomera	2	-20	13	-15	- 9	13
San Fernando	42	-72	10	-17	-29	45
Tokyo	-47	-89	-41	-34	-54	36
Naini Tal	49	-64	84	28	-40	8
Arequipa	-59	-44	-65	- 4	-16	-53
Shiraz	77	-39	115	46	5	64
Curacao	-102	-55	-39	-49	-17	-21
Jupiter	-21	5	0	- 8	- 4	- 6
Villa Dolores	-23	-43	9	-15	-19	- 4
Maui	53	-152	-138	9	-77	-72

Dr. Walter Kohnlein's work on geodetic reference surfaces will be reported in a forthcoming paper. Recently he undertook an analysis of the geometrical structure of the Earth's outer gravitational field. The purpose of this investigation is a comparison of results arrived at by conventional and by satellite methods. A computer program designed to give detailed numerical results is being developed. Dr. Kohnlein was also working on a redetermination of the American and European datum shifts.

Chi-yuen Wang continued his work on a possible interpretation of gravitational anomalies as revealed by the motion of satellites. He found the correlation coefficient between the elliptcy term of the geopotential and the fluctuations in the heat flow over the Earth's surface to be -0.82. This result may prove to be important to an understanding of the internal structure of our planet. Mr. Wang is investigating various mathematical models of the interior of the Earth to test their capability of explaining the observed correlations just mentioned.

SPECIAL PROJECTS

As we indicated in our proposal of January 1963 for continuation of the satellite-tracking program, the unique capabilities of the station network and of individual stations lead to occasional requests for special observing assistance. These requests involve no significant additional costs; give the field staff practice in special techniques; and provide scientific data that would not be available otherwise. Therefore we find it advantageous to cooperate in these special studies, some of which are described below. (See figure 1.)

Solar system

Dr. Joachim Schubart has studied the orbits of minor planets, the mean motions of which are nearly commensurable with that of Jupiter. In such cases the ordinary perturbation techniques of celestial mechanics fail, and special methods have to be developed. Much information regarding the nature of perturbed motion can be gained by deriving the secular and critical part of the disturbing function. Dr. Schubart has devised a computer program that constructs level curves of this function. These curves, in turn, can automatically be plotted. He applied this method to the motion of numerous minor planets such as those belonging to the Hecuba and Hilda groups.

Dr. Giuseppe Colombo and Dr. G. Fiocco of MIT collaborated on an interpretation of recent optical radar experiments that indicated the existence of a scattering layer in the upper atmosphere at an altitude between 110-140 km. They concluded that progressive fragmentation of meteoroids may well be the cause of this phenomenon. This would imply that most meteoroids are very weak in structure and that the radius of the smallest crystal that forms the structure of meteoroids lies between 0.1 and 0.01 micron.

Comet study

Comet Pereya, 1963 ϵ, was photographed by several Baker-Nunn stations between mid-September and early November. Most films came from the stations in South Africa, Australia, Spain, Peru, Argentina, and Hawaii. The most suitable films were measured with a microdensitometer in order to determine whether accurate measurements of the total light intensity of the comet head could be determined from the images recorded on Baker-Nunn film. A plexiglass defocusing lens has been constructed for the Baker-Nunn camera, and the Florida station has taken a few films with it.

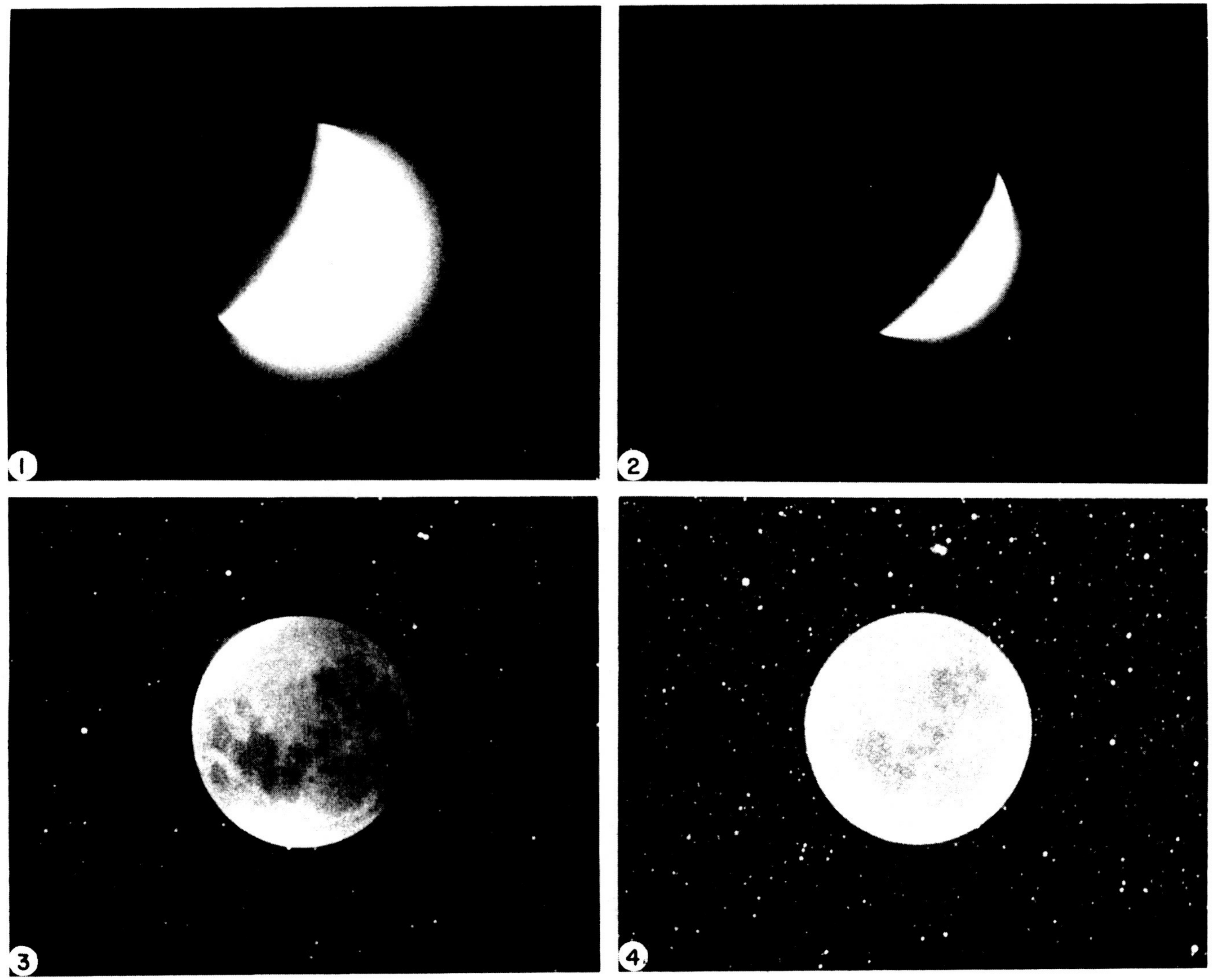

Figure 1.--On occasion the Baker-Nunn cameras track natural as well as manmade satellites. The so-called "invisible" lunar eclipse of December 1963 was successfully photographed by the New Mexico camera station. The first two pictures show the earth's shadow crossing the moon. The second tow, taken at totality, record the fine detail on the face of the moon. The last two were published in a recent issue of Sky and Telescope.

Micrometeorites project

The micrometeorites project of Drs. Colombo, and Lautman, and Dr. Shapiro of the MIT Lincoln Laboratory led to further results, some of which were reported at a meeting of the Italian Physical Society. Present calculations allow these authors to estimate the radial distribution of flux and density of captured dust as a function of the area-mass ratio, the velocity at infinity, and the density at infinity. They found that the density of cosmic dust may be enhanced in the vicinity of the Earth by a factor 10^4--which is in reasonable agreement with observational evidence. Present efforts are directed toward increasing the accuracy of the results and determining the distribution of the particles in 3-space.

Flare-star observations

We have continued flare-star observation, using the method described in the previous report. During October and December we attempted 268.5 hours of observation and actually observed for 155 hours. Photographs from Baker-Nunn camera stations aid in the study of flare stars (see figure 2). Measurement of films and reduction data are proceeding slowly, but several small events were reported by the field stations during the October period of observation. Correlation of these data is now proceeding.

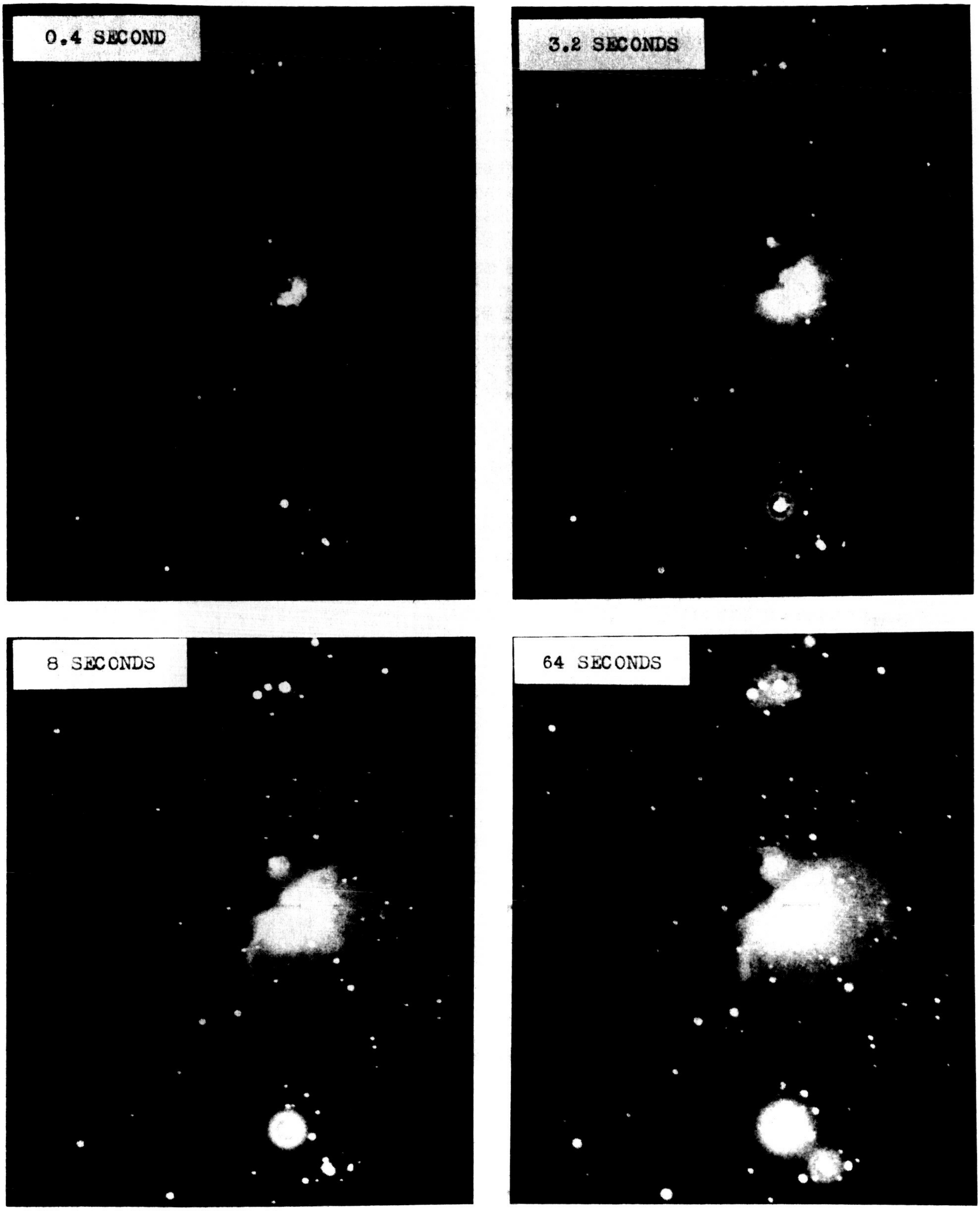

Figure 2.--The Australian camera station made these unusual time-exposure photographs of the Orion Nebula to measure limiting magnitude as a prelude to flar star studies also funded by grant NsG 87/60.

EDITORIAL AND PUBLICATIONS

The Satellite Tracking Program issued the following Special Reports during this six-month period:

No. 127 -- Altitude Determination from Specular and Diffuse from Reflection by Cylindrical Artificial Satellites by R. H. Giese.

No. 128 -- Ultraviolet Synthesis of Adenosine Triphosphate under Possible Primitive Earth Conditions by Cyril Ponnamperuma, Carl Sagan, and Ruth Mariner.

No. 129 -- Laplace Coefficients and Their Newcomb Derivatives by I. G. Izsak.

No. 130 -- Catalogue of Satellite Observations (C-34), prepared by B. Miller.

No. 131 -- Catalogue of Satellite Observations (C-35), prepared by B. Miller.

No. 132 -- Catalogue of Satellite Observations (C-36), prepared by B. Miller.

No. 133 -- The Determination of Absolute Directions in Space with Artificial Satellites by G. Veis

No. 134 -- On the Distribution of Surface Heat Flows and the Second Order Variations in the External Gravitational Field by Chi-yuen Wang.

No. 135 -- Formulae and Tables for the Computation of Lifetimes of Artificial Satellites by Luigi G. Jacchia and Jack Slowey.

No. 136 -- Atmospheric Heating in the Auroral Zones: A Preliminary Analysis of the Atmospheric Drag of the Injun III Satellite by Luigi G. Jacchia and Jack Slowey.

No. 137 -- Catalogue of Precisely Reduced Observations (P-9), compiled by Phyllis Stern.

No. 138 -- Catalogue of Precisely Reduced Observations (P-10), compiled by Phyllis Stern.

No. 139 -- Optical Radar Results and Meteoric Fragmentation
by G. Colombo and G. Fiocco

No. 140 -- Construction of Newcomb Operators on a Digital Computer
by I. G. Izsak, J. M. Gerard, R. Efimba and M. P. Barnett.

In addition, numerous scientific papers deriving from the Satellite Tracking Program were published in scientific journals. These will be listed in the next semiannual report.